U1: Introduction

Classifications

- Key -> Symmetric & Asymmetric
- Process -> Stream (Cipher) & Block (AES, DES)
- Methods -> Transposition & Substitution

Goals

- C - Confidentiality
- I - Integrity
- A - Availability

Attacks

- Confidentiality
  - Snooping (P)
    - Eavsdropping on the messages between 2 parties but not affecting the message itself
  - Traffic Analysis (P)
    - Analysis on the frequency of the packets that are occur in the message and compare it to the frequency of commonly occurring data/packets (Traffic Analysis)
- Integrity
  - Modification (A)
    - Modification to the message when its enroute to destination
  - Masquerading (A)
    - Acting as the intended source/destination to hijack the connection
  - Replaying (A)
    - Using packets intercepted by the attacker from the source and replaying it later
  - Repudiation (A)
    - When a conversation/ transfer takes place but one/ both parties does not acknowledge it ever happening (involves manipulation in logs)
- Availability
  - Denial Of Service (A)

    - Over flooding a server with so many requests such that clients cannot access the server

> **Note**
>
> - A - Active
>   - Alteration to the message
>   - Hard to detect
>   - Easy to prevent
> - P - Passive
>   - No alteration to the message
>   - Easy to detect
>   - Hard to prevent

Services

- Confidentiality
- Integrity
- Authentication
- Non Repudiation
- Access Control

Mechanisms

- Confidentiality
    - Encipherment
    - Routing Control
    - Traffic Padding
- Integrity
    - Encipherment
    - Digital Signature
- Authentication
    - Encipherment
    - Digital Signature
    - Authentication Exchange
- Non Repudiation
    - Digital Signature
    - Data Integrity
    - Notarization
- Access Control

    - Access Control Mechanism

U2: Algorithms

Block Ciphers

Feistal vs Non Fiestal

- Fiestal: Consists of self invertible, invertible, and non invertible components
- Non Fiestal: Only consists of non invertible components

Fiestel Structure

- 16 rounds: Each round uses different generated keys from the original key
- Split into LHS and RHS bits
- Formula:
    - $RHS_1 = LHS_0 xor(F_{k1}\{RHS_0\})$
    - $LHS_1 = RHS_0$
- Last round: swap LHS and RHS

Fiestel Properties

- Block size
- Key Size
- Number of rounds
- Subkey generation
- Round function
- Fast encryption/decryption
- Ease of analysis

Attacks

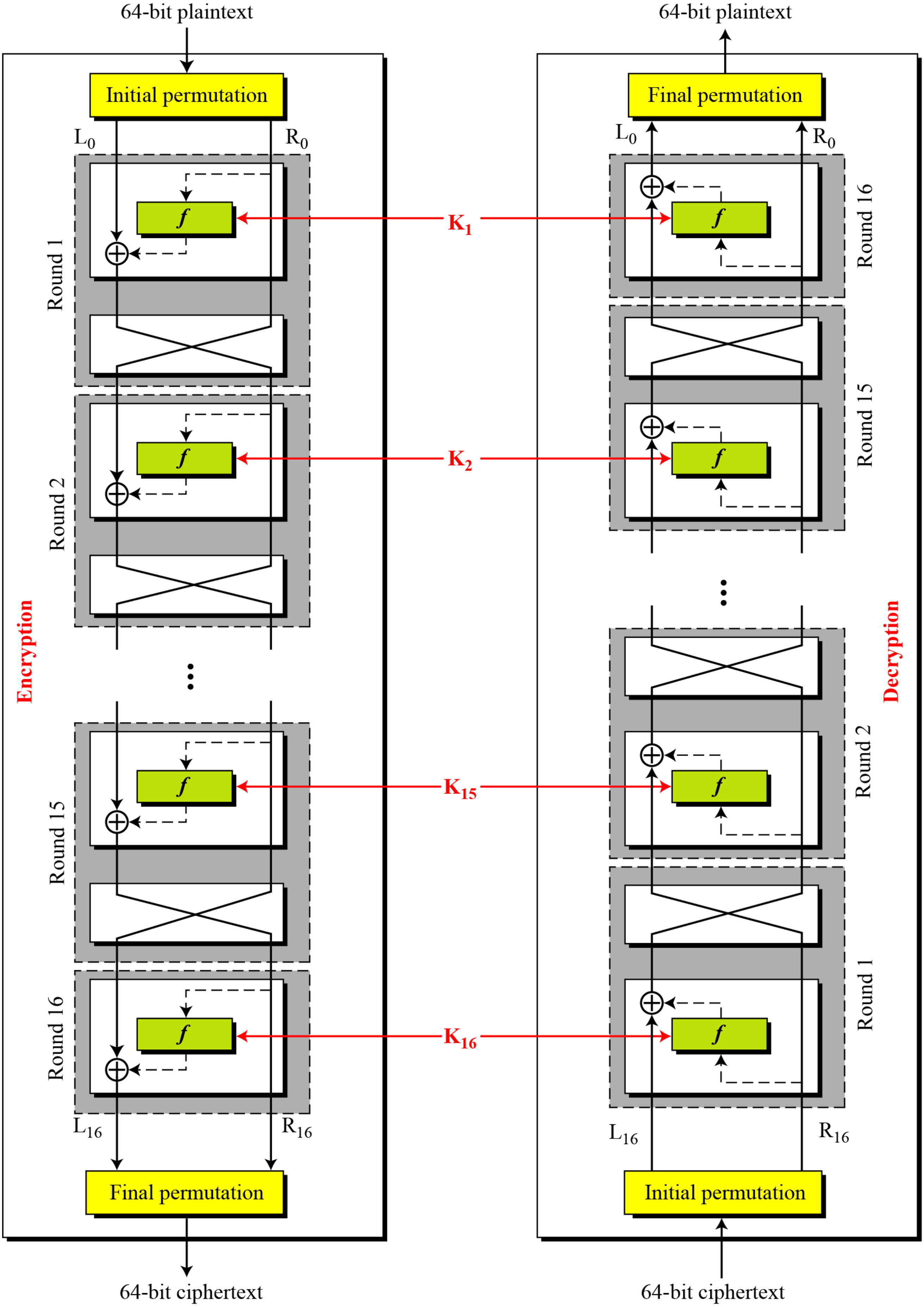
- Linear Cryptanalysis
- Differential Cryptanalysis

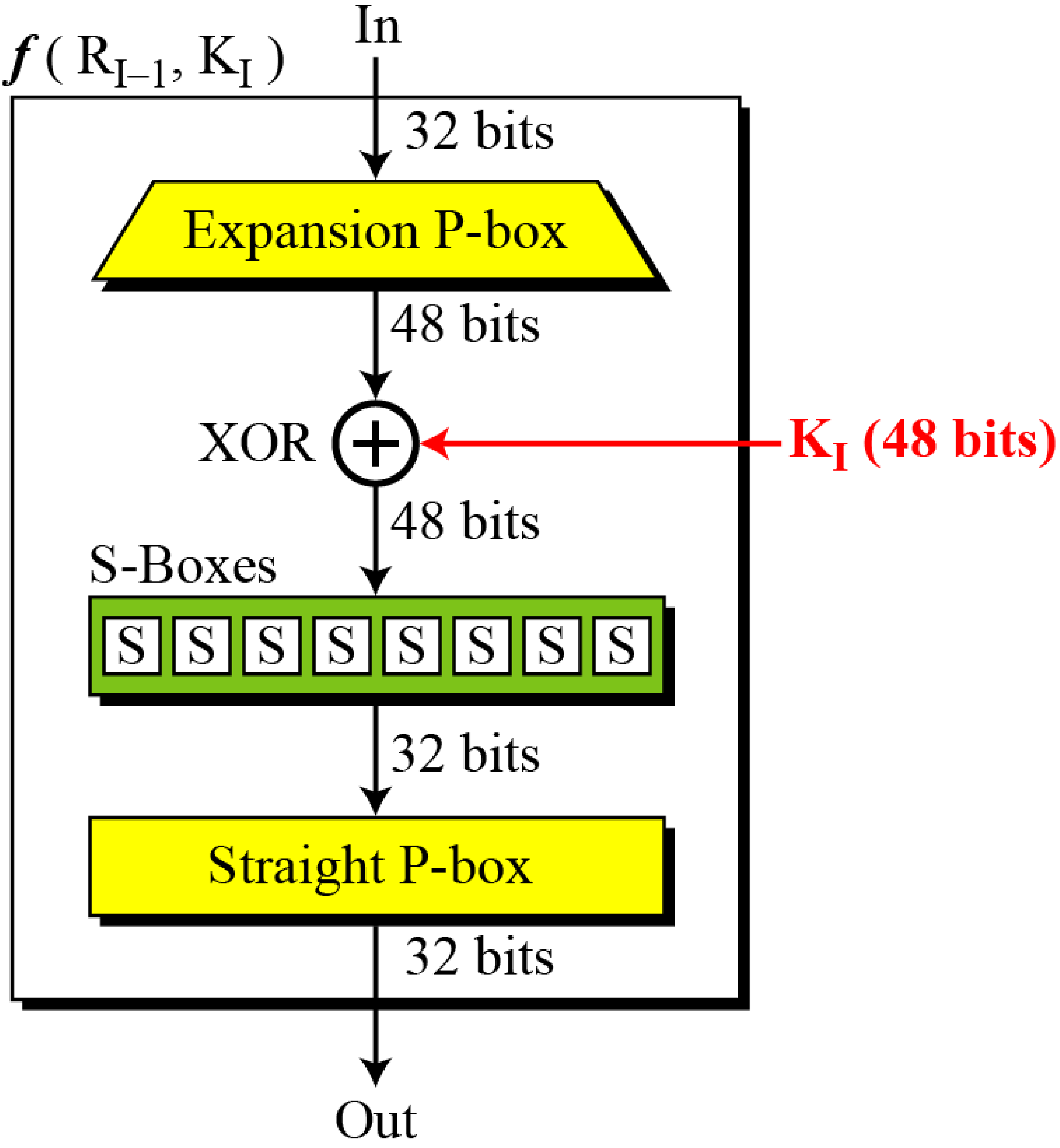
DES

Properties

- Block cipher
- No. Rounds - 16
- Bits:
  - Input - 64 bits
  - Output - 64 bits
  - Main key - 64 bits
  - Subkey - 56 bits (After Parity drop)
  - Round key - 48 bits
- Avalanche Effect
  - 1 bit change in PT - 34 bits change in CT on avg
  - 1 bit change in key - 35 bits change in CT on avg

Structure


64-bit plaintext
64-bit plaintext
Initial permutation
Final permutation
L0
R0
L0
R0
Round 1
Round 16
f
K1
Round 2
Round 15
K2
Encryption
Decryption
Round 15
Round 2
K15
Round 16
Round 1
K16
L16
R16
L16
R16
Final permutation
Initial permutation
64-bit ciphertext
64-bit ciphertext



Encryption

1. Initial Permutation (64 bits -> 64 bits)
2. 16 rounds (64 bits -> 64 bits)
3. 32 bit swap (64 bits -> 64 bits)
4. Inverse Initial Permutation (64 bits -> 64 bits)

Decryption

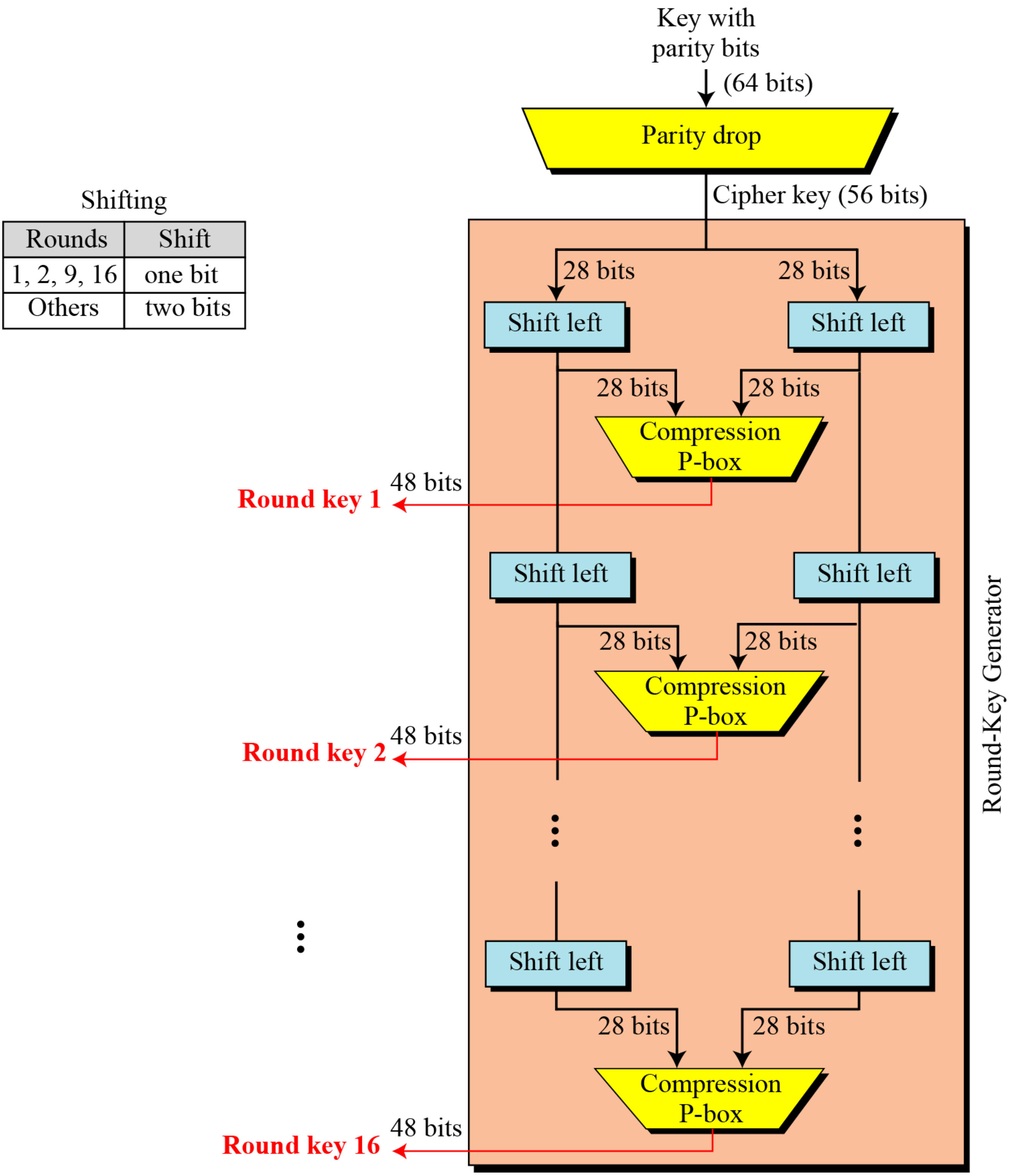
1. Initial Permutation (64 bits -> 64 bits)
2. 16 rounds (64 bits -> 64 bits) - with inverted order of keys
3. 32 bit swap (64 bits -> 64 bits)

4. Inverse Initial Permutation (64 bits -> 64 bits)

Round

1. Split into LHS and RHS bits
2. Round Formula:
   - $RHS_1 = LHS_0 \, xor \, (F_{k1}\{RHS_0\})$
   - $LHS_1 = RHS_0$
3. F -> function (Mangler)
   1. Expansion Permutation (32 bits -> 48 bits)
   2. y = input xor key (48 bits -> 48 bits)
   3. Substitution S Box - 8 (6b -> 4b) S-Boxes (48 bits -> 32 bits)
   4. Transposition P box (32 bits -> 32 bits)

Key Generation



Shifting

Rounds	Shift
1, 2, 9, 16	one bit
Others	two bits

1. Split half (32b:32b split)
2. Drop bits - 8, 16, 24 ... (64 bits -> 56 bits)
3. Left circular shift both (56b -> 56b)
    - 1,2,9,16 rounds -> 1 shift
    - Rest rounds -> 2 shifts
4. Compression Permutation (56b -> 48b)

Weakness

- Weakness in Key

- Weakness in S-Box
- Weakness in P-Box

Possible attacks

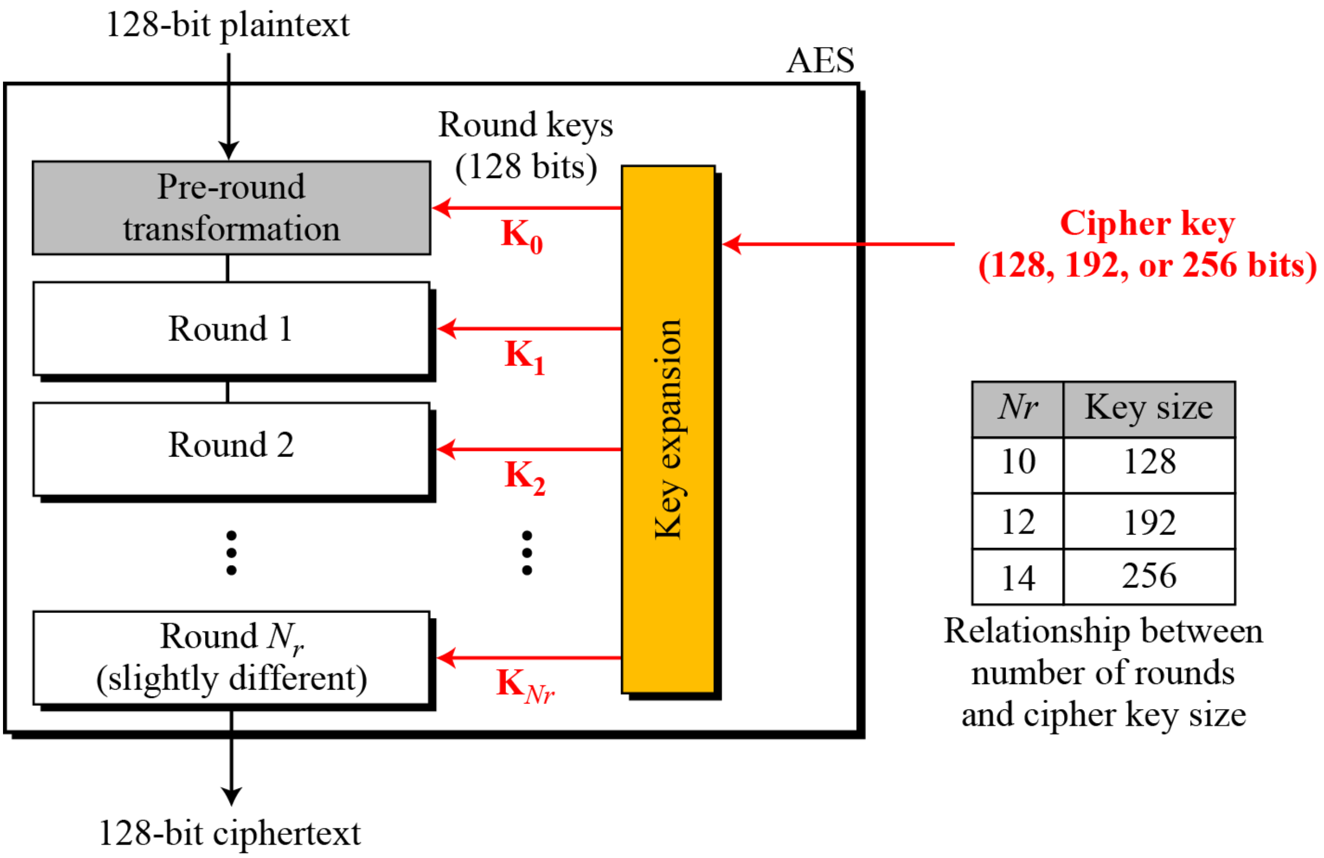
- Brute Force - Short cipher key combined with key complement weakness - just 2^55 encryption to try by brute force
- Differential Cryptanalysis - Resistant due to 16 rounds
- Linear Cryptanalysis - vulnerable
- Man in the middle - vulnerable for double DES

AES

Properties

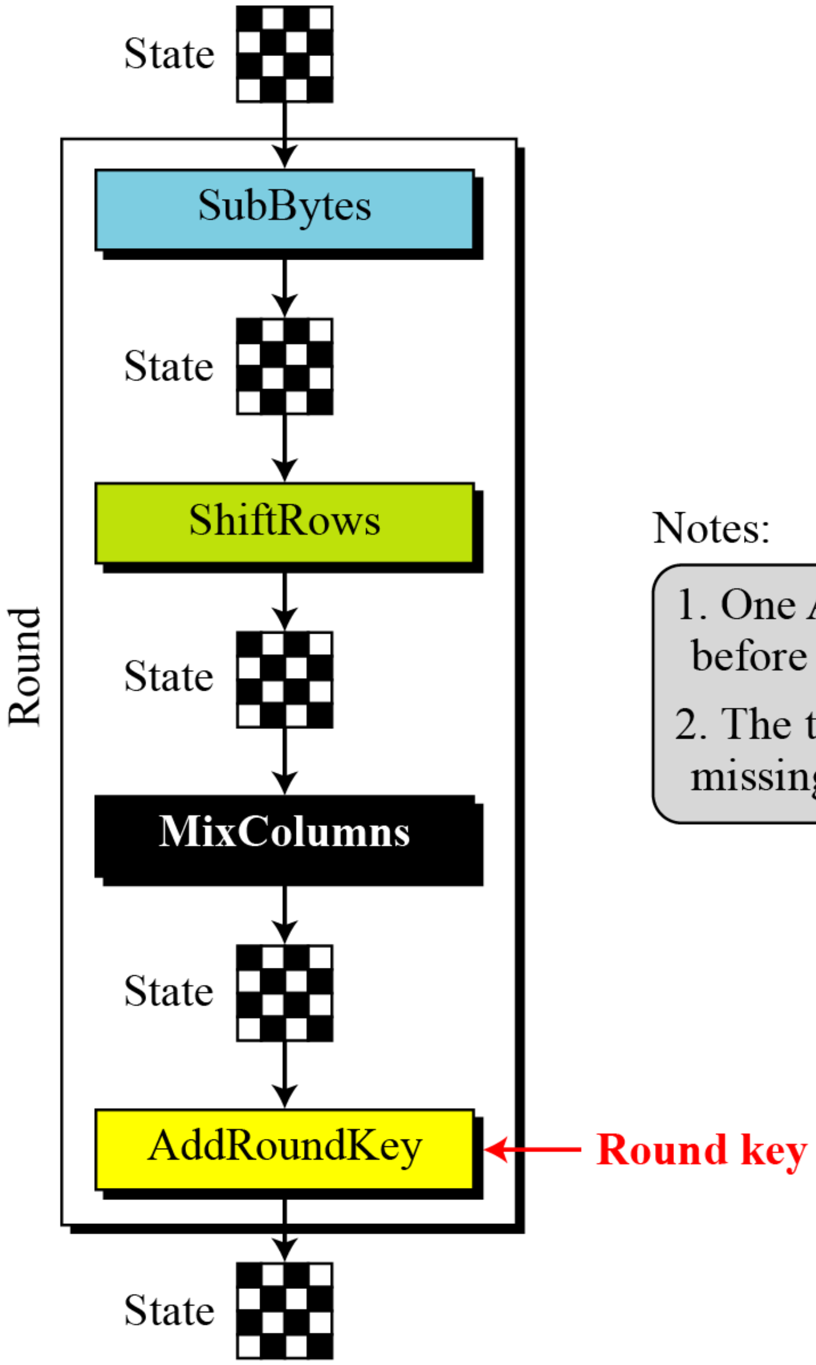
- Non Fiestel
- Symmetric Block Cipher
- No. Rounds depends on variant (128, 192, 256) -> (10, 12, 14)
- Bits Size
  - Input - 128 bits
  - Output - 128 bits
  - Key - M bits (M -> variant of AES)
  - Round Key - 128 bits (16 bytes)

Structure



Nr	Key size
10	128
12	192
14	256

Relationship between
number of rounds
and cipher key size


State
SubBytes
State
ShiftRows
State
MixColumns
State
AddRoundKey
Round key
State
Round
Notes:
1. One AddRoundKey is applied before the first round.
2. The third transformation is missing in the last round.

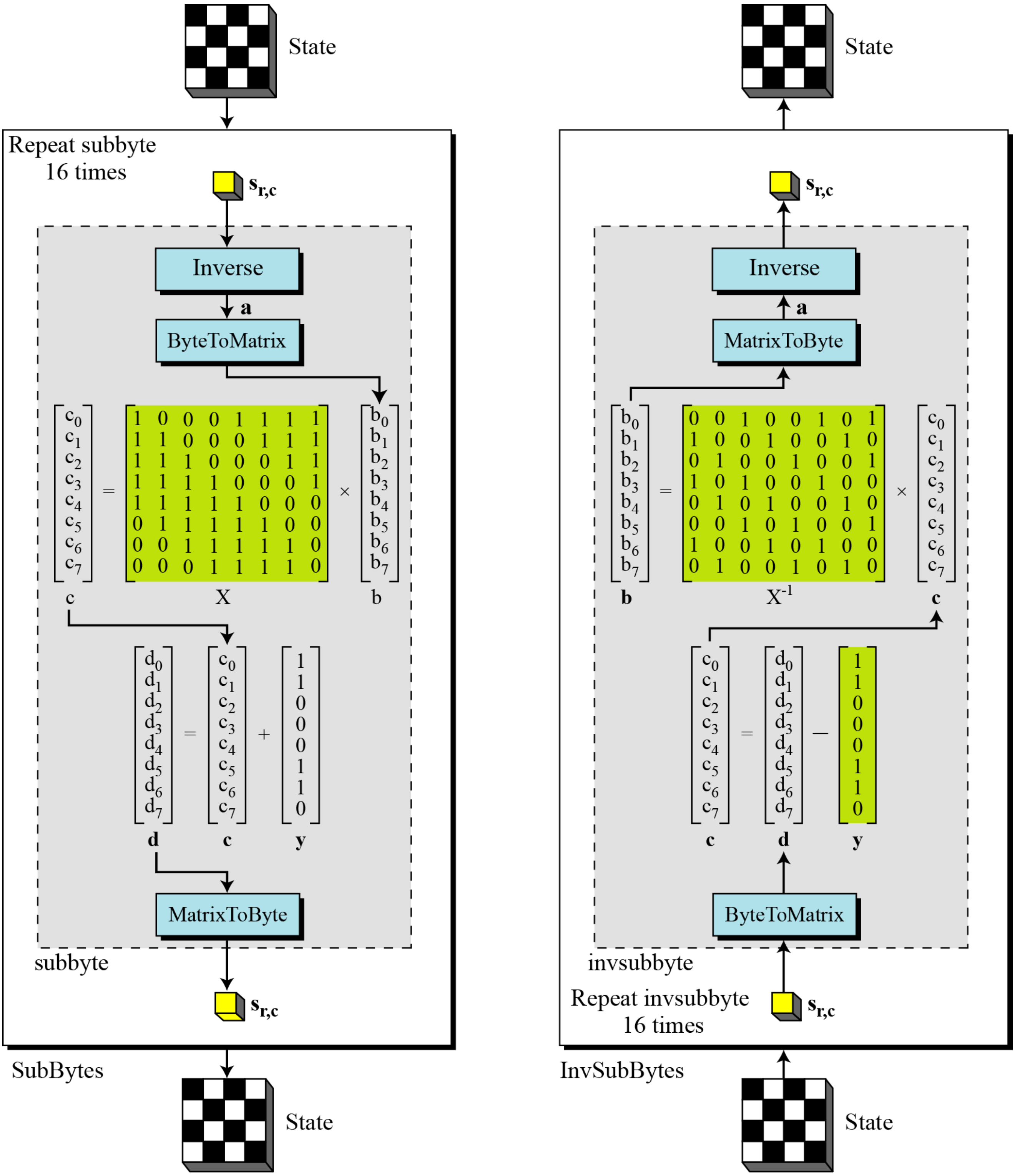
Encryption

1. Initial transformation (Round 0 key) - Add Round key operation
2. Round [0 to N - 1] - 4 transformations
3. Round [N] - 3 transformations

Decryption

1. Initial transformation (Round 0 key) - Add Round key operation
2. Round [0 to N - 1] - 4 transformations (Key order reversed)
3. Round [N] - 3 transformations

Round

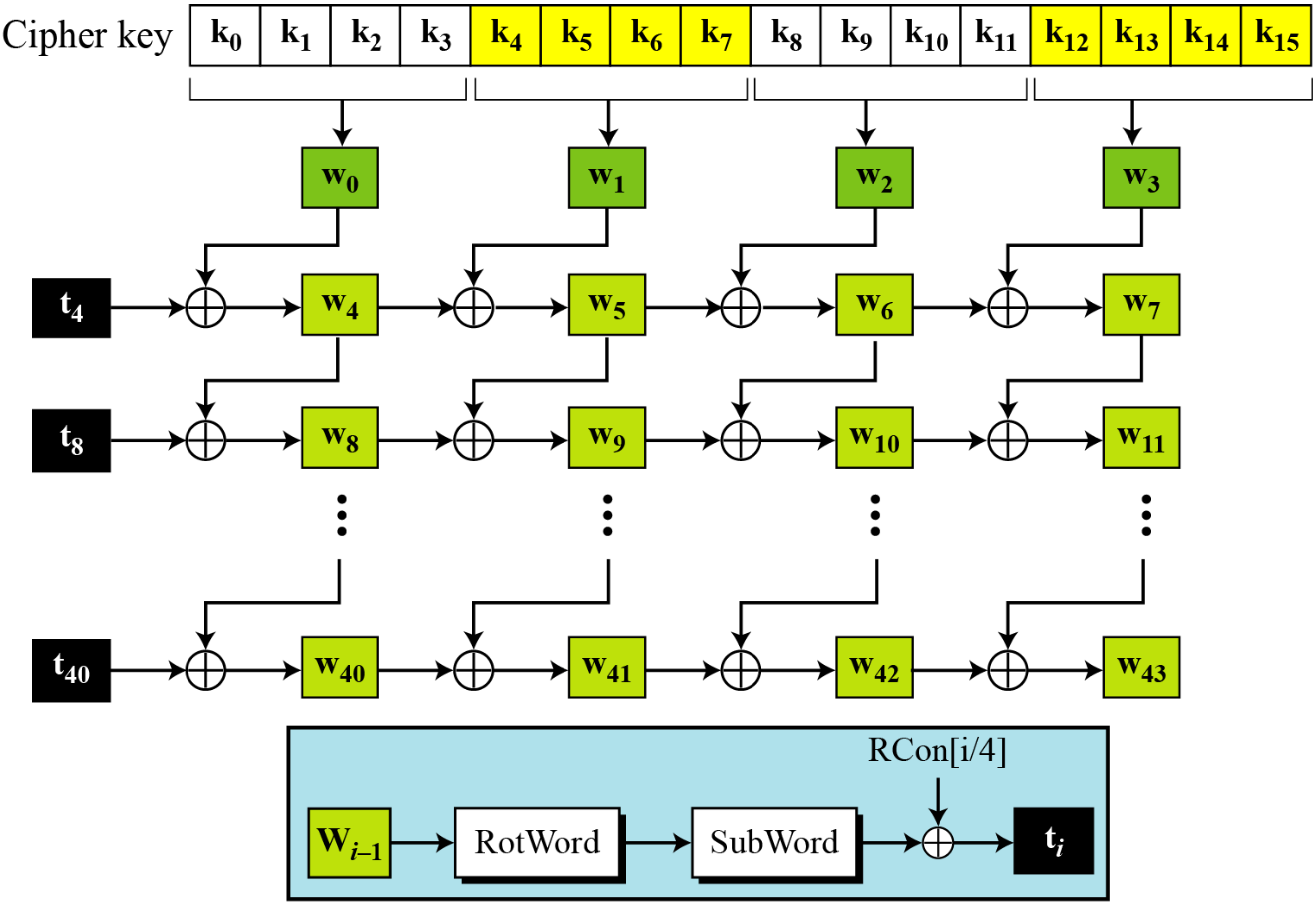


1. Substitute bytes - S-Box (Sub Byte)
2. Shift rows
    1. 0,1,2,3 - Untouched
    2. 1,2,3,0
    3. 2,3,0,1
    4. 3,0,1,2
3. Mix columns (Not there in last round)

```
    matrix →
    [2,3,1,1],
    [1,2,3,1],
    [1,1,2,3],
    [3,1,1,2]
```

4. Add Round Key (4 words from key scheduler) - Each word xor to each column

Key Generation



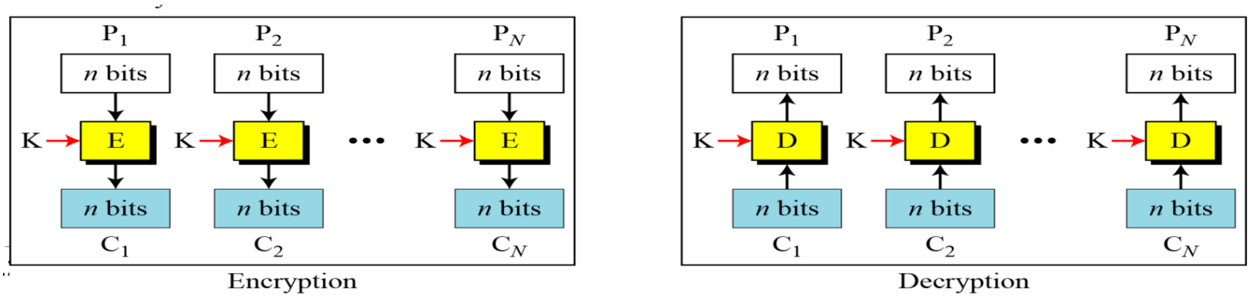
Making of t_i (temporary) words $i = 4\ N_r$

Security

- Brute Force - More secure than DES
- Statistical Attacks - Fails
- Differential and Linear Attacks - none yet

Mordern Block Ciphers

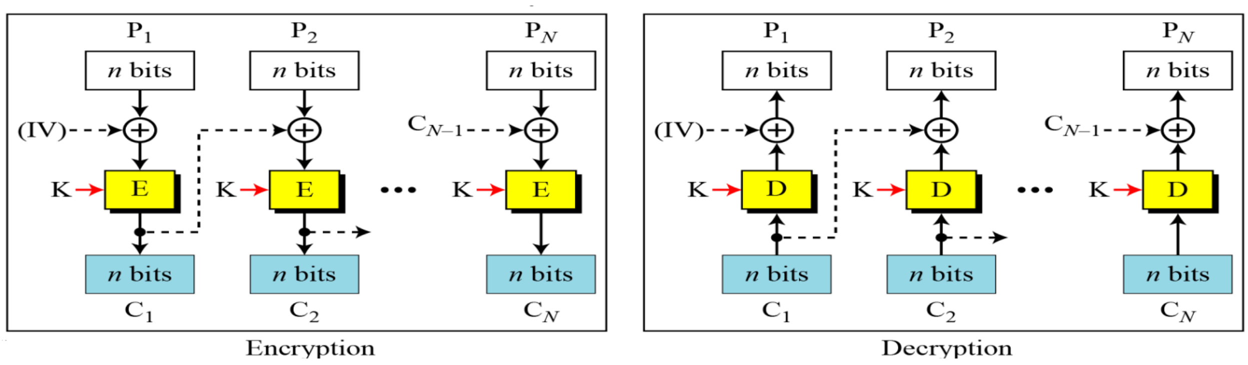
ECB (Electronic Codebook)

- 

- No Error Propogation
- C_i = E_k (P_i)\ &\ P_i = D_k (C_i)

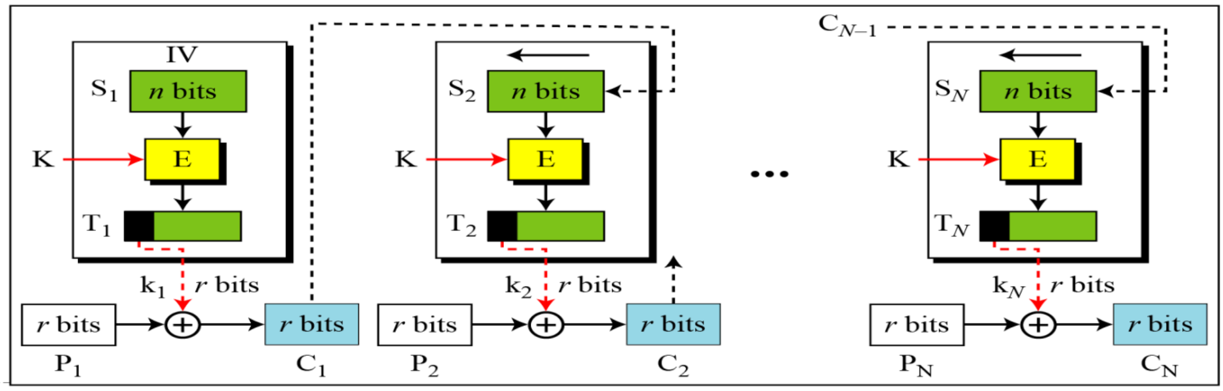
> Note
>
> ## Ciphertext Stealing
>
> - Allows usage of ECB without padding
> - $X = E_k(P_{N-1}) \rightarrow C_N = head_m(X)$
> - $Y = P_N|tail_{n-m}(X) \rightarrow C_{N-1} = E_k(Y)$

CBC (Cipher Block Chaining)

- 

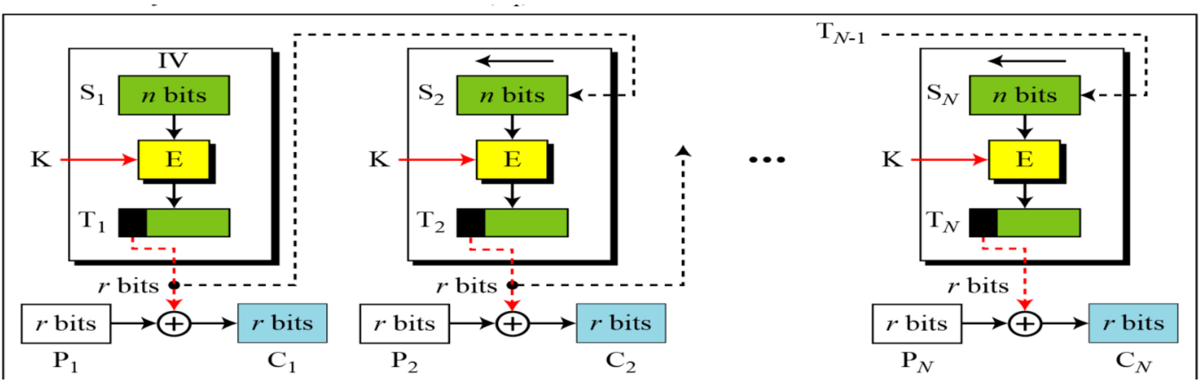
- `xor` between `PT` and encryption block with input from previous block `CT`
- Initial Vector should be known be sender and reciever
- Error propogation possible
- Ciphertext Stealing can be applied here also

CFB (Cipher Feedback)

- 

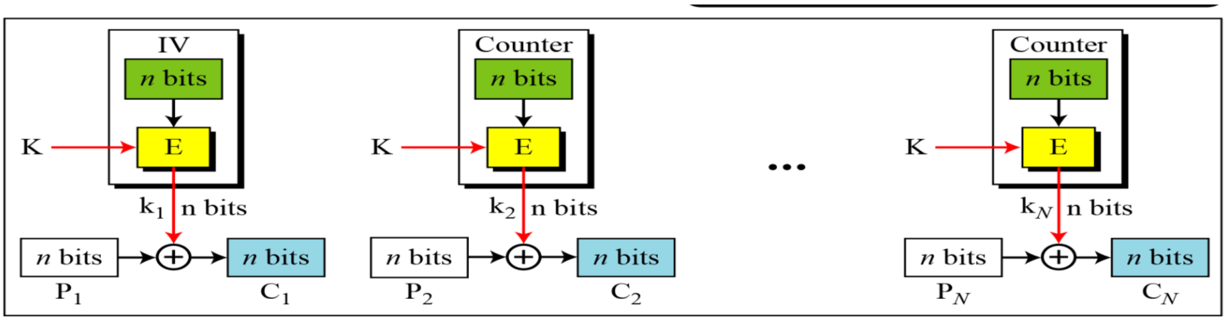
- Used when block sizes are too small for secure ciphers like AES/DES
- PT is `xor`ed with output of round block to get CT. This CT is used as input to block in next round
- Round block encrypts input with key to create output

OFB (Output Feedback)

- 

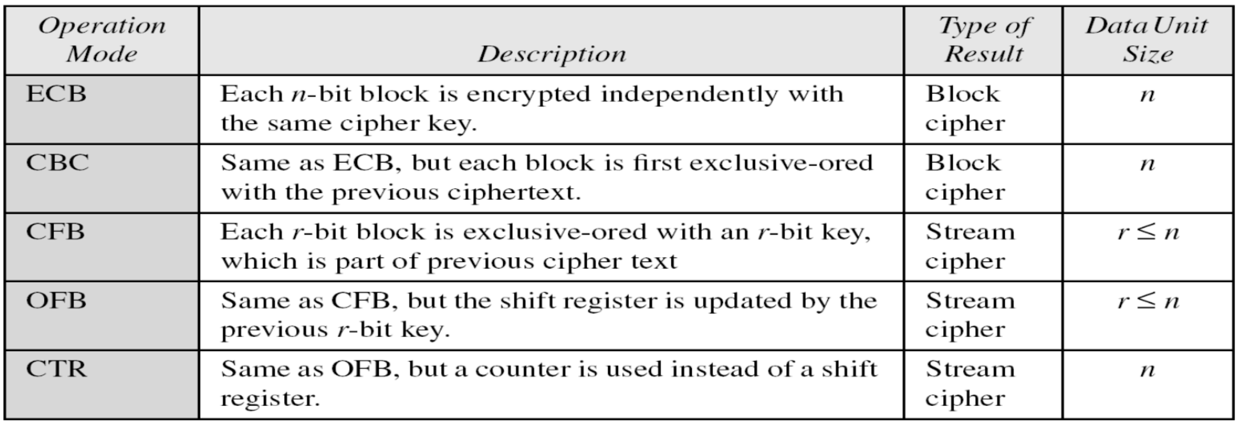
- Similar to CFB, just ouput of round block is used as input to next round block

CTR (Counter)

- 

- A counter is used
- It's incremented for each round and encrypted with round key

Summary

- 

Operation Mode	Description	Type of Result	Data Unit Size
ECB	Each n-bit block is encrypted independently with the same cipher key.	Block cipher	n
CBC	Same as ECB, but each block is first exclusive-ored with the previous ciphertext.	Block cipher	n
CFB	Each r-bit block is exclusive-ored with an r-bit key, which is part of previous cipher text	Stream cipher	$r \leq n$
OFB	Same as CFB, but the shift register is updated by the previous r-bit key.	Stream cipher	$r \leq n$
CTR	Same as OFB, but a counter is used instead of a shift register.	Stream cipher	n

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Message Integrity

Hash Function Critera

- Preimage resistance
- Second Preimage resistance
- Collision resistance

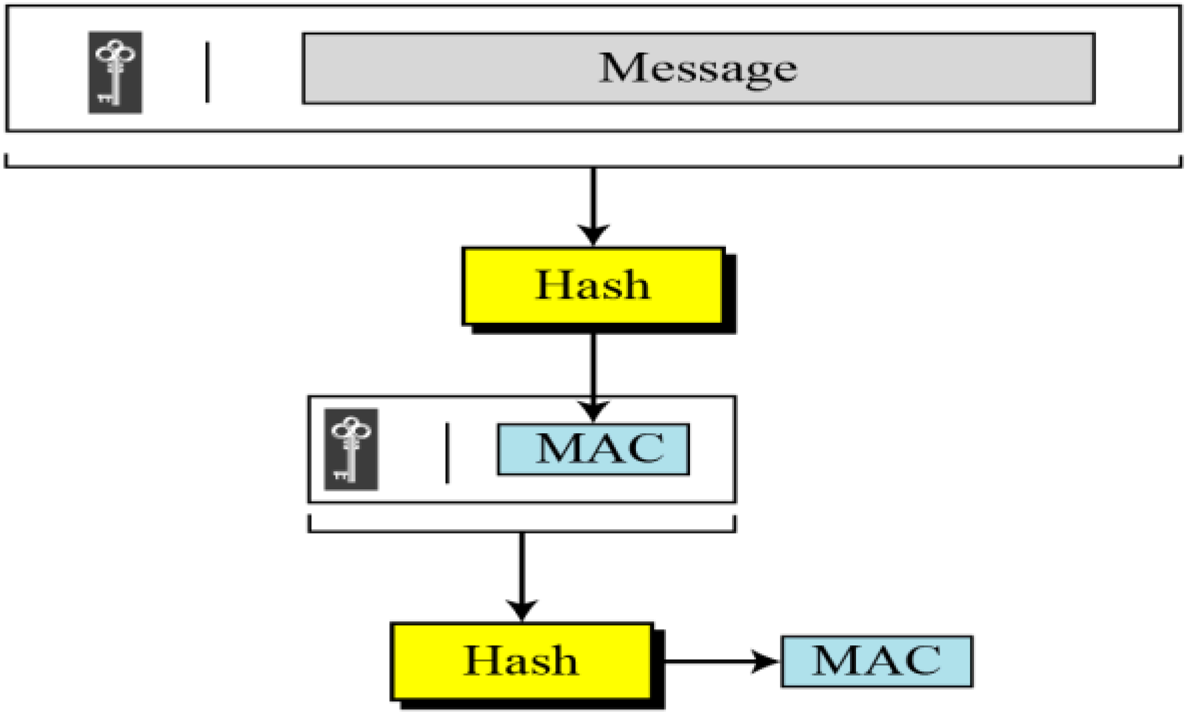
MDC (Modification Detection Code)

- This is the output of cryptographic hash functions
- Proves integrity of message
- The message and MDC is send via channel

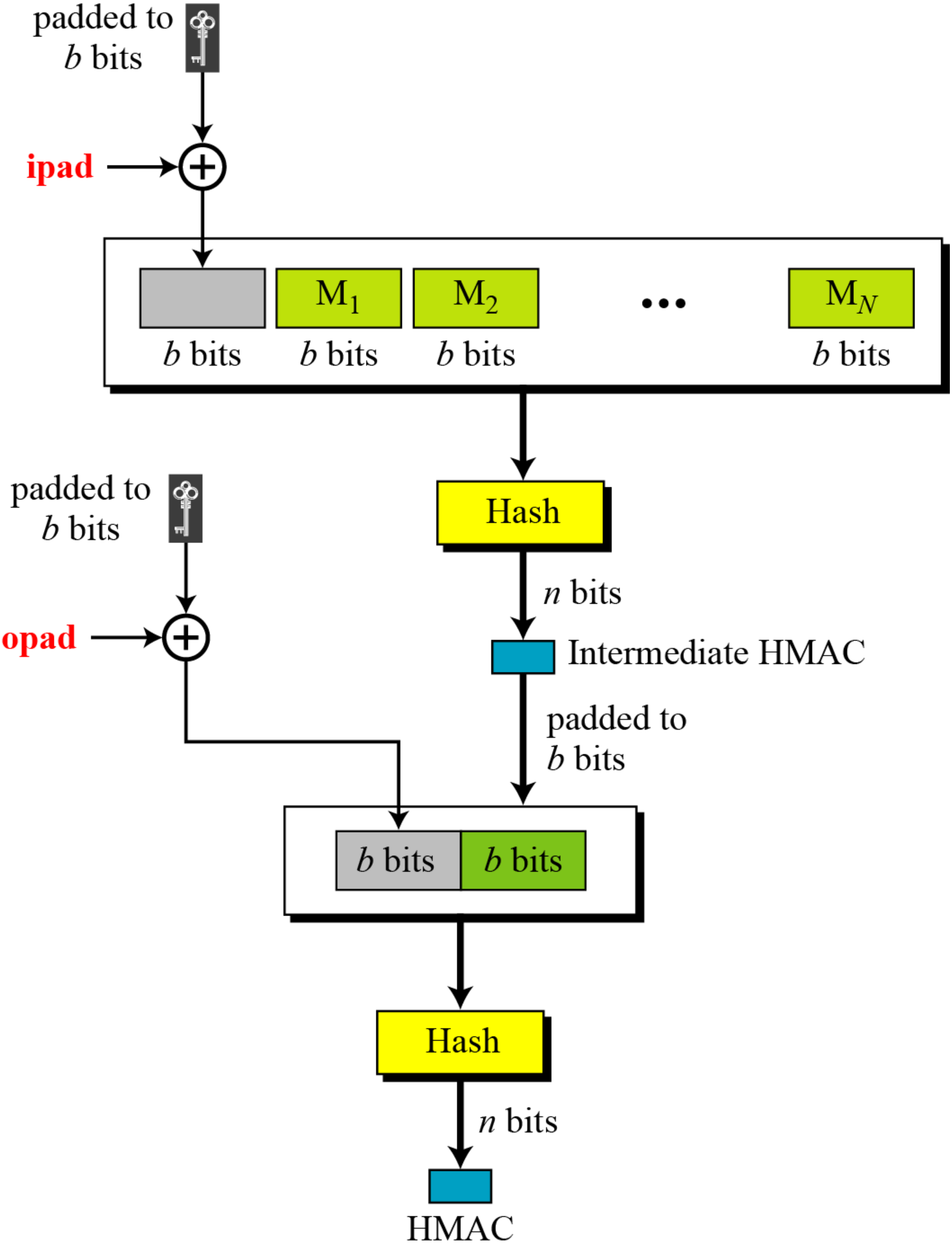
MAC

- This is created by using a hash function with a shared key
- The message and MAC is send via channel

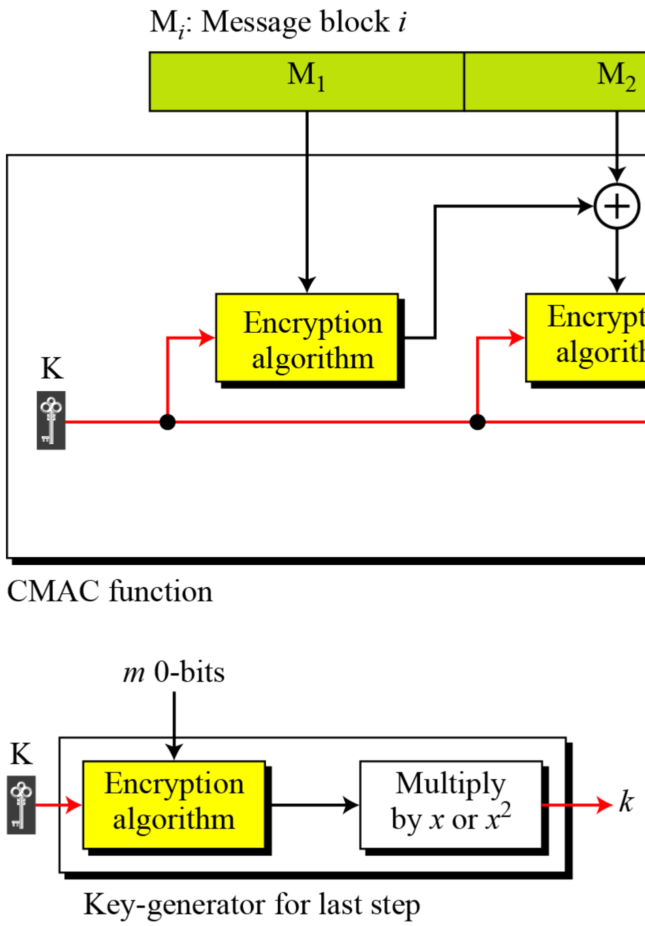
Nested MAC



HMAC


padded to
b bits
ipad
M1
M2
...
MN
b bits
b bits
b bits
b bits
Hash
n bits
Intermediate HMAC
padded to
b bits
opad
padded to
b bits
b bits
b bits
Hash
n bits
HMAC

CMAC


M_i: Message block i
M_1
M_2
•••
M_N
k
K
Encryption algorithm
Encryption algorithm
•••
Encryption algorithm
Select n leftmost bits
CMAC function
n-bit CMAC
m 0-bits
K
Encryption algorithm
Multiply by x or x^2
k
Key-generator for last step